Relative Role of Groundwater Versus Surface Water in the Gale Crater Region

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Overview

Although our understanding of past hydrologic conditions on early Mars has increased, the relative importance of groundwater versus surface water is still not well understood. In this investigation, we seek to quantify past ground- and surface-water flow on Mars through fine-scale mapping of valley networks, combined with hydrologic analysis and modeling.

We mapped valley networks at 6 m/pixel on the rims of 9 craters (**Fig. 1**) along a transect, ending with Gale crater (**Fig. 2, 3**). We measured the elevation of valley network terminations (VNTs) and found that the VNTs for each crater tended to cluster around a similar elevation (**Fig. 4**). We then compared these elevations to crater wall topographic profiles, both from MOLA and CTX DEMs (**Fig. 5**). These elevation lines did not coincide with the crater floor or with morphologic variation of the crater wall, suggesting these may indicate past lake levels.

We also compared our VNTs to Horvath and Andrews-Hanna's (2017) groundwater model output in the Gale region, and found that our VNTs best corresponded with an aridity index of 1.5 (**Fig. 6**) though an aridity index of 3.5 also corresponds well with the lower inferred lake level in Gale Crater (**Fig. 7**).

Methods

We used CTX imagery to map valley networks (e.g., Fig. 1) around the rims of 9 craters along a SW-NE transect, ending at Gale Crater (Fig. 2). We marked and numbered the terminal end of each valley network. Then, using the planet-wide MOLA DEM, we recorded the elevation of each VNT. We took the average of these elevations within each crater to determine the crater's inferred paleolake level and mapped these inferred lake levels onto the topographic profile of our SW-NE transect (Fig. 3). We also created CTX DEMs of crater rims using ISIS3 and the Ames Stereo Pipeline in 8 of the 9 craters. Stereo pairs were selected using USGS PILOT.

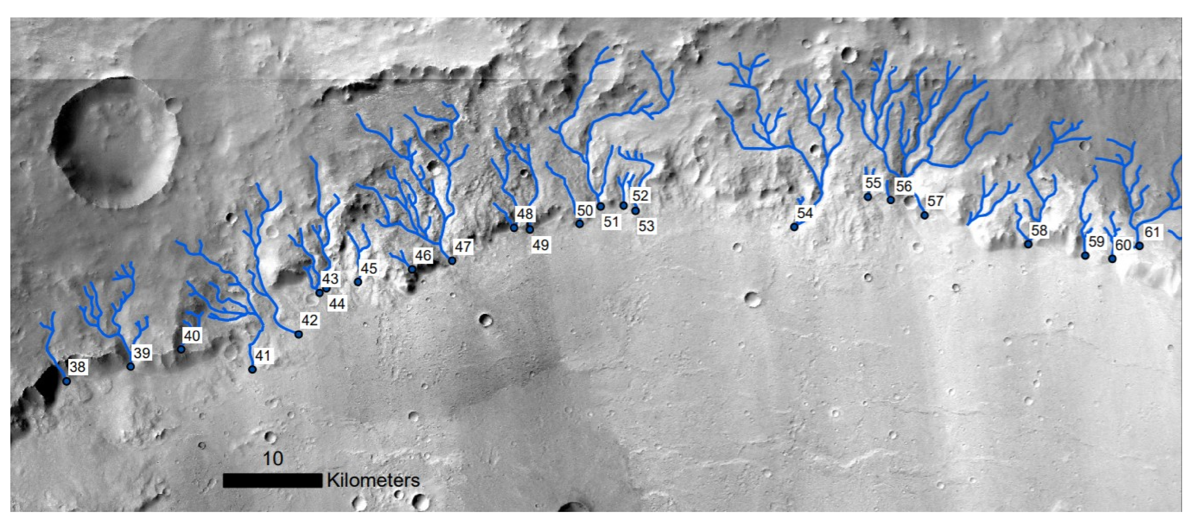

Fig. 1: Mapped valley networks (blue) on the north rim of Herschel crater, with valley network terminations (VNTs) marked in navy.

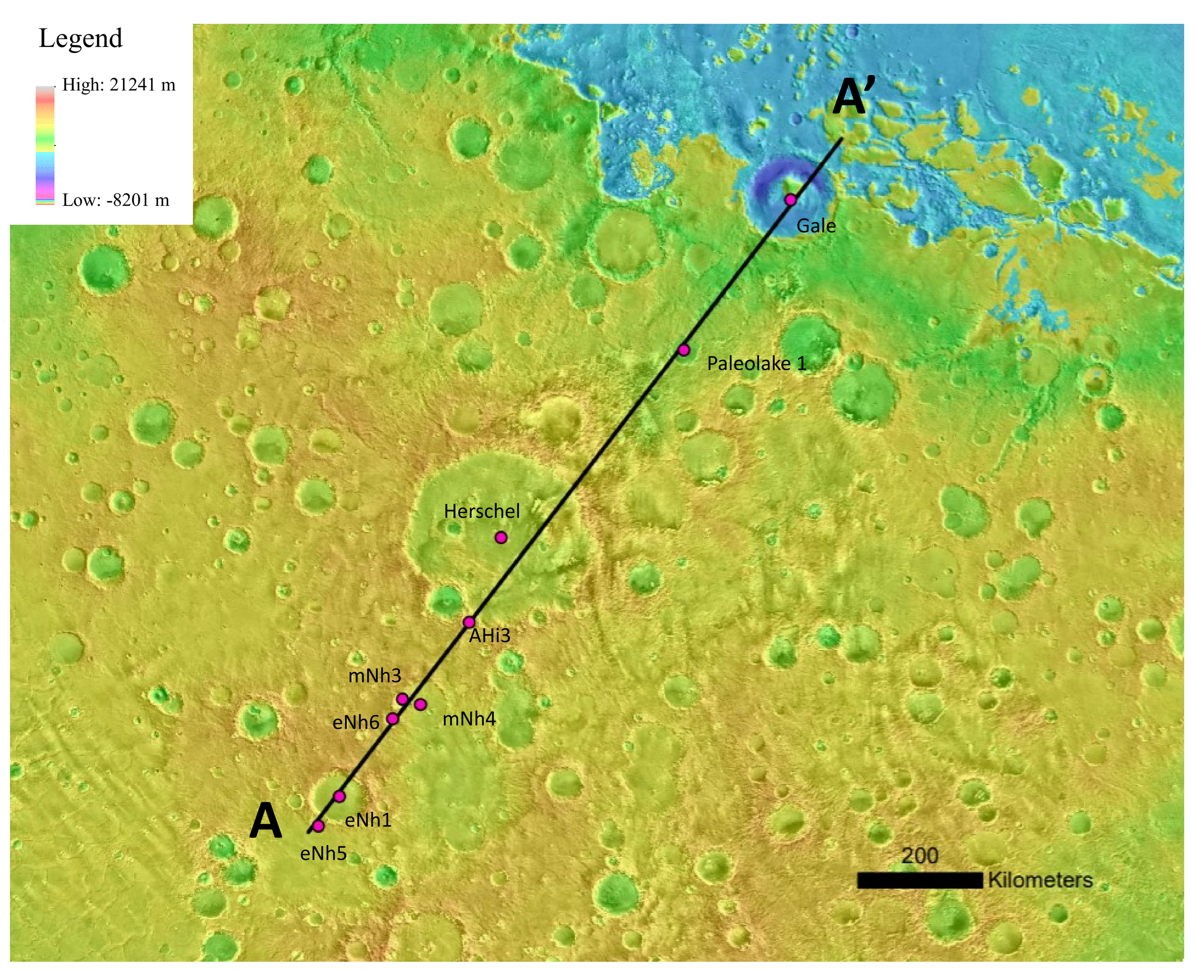

Fig. 2: Transect line (black) in region of study, with endpoints and the 9 craters of interest labeled. Background color indicates elevation (from MOLA DEM), with red indicating high elevation and blue indicating low elevation (see legend).

References
[1] Sharp R. P. and Malin M. C. (1975) *GSA Bulletin, 86,* 593-609. [2] Carr M. H. and Clow G. D. (1981) *Icarus, 48,* 91-117. [3] Baker V. R. and Partridge J. B. (1986) *J. Geophys. Res., 91,* 3561-3572. [4] Howard A. D.et al. (2005) *J. Geophys. Res., 110,* E12S14. [5] Irwin R. P. et al. (2005) *J. Geophys. Res., 110,* E12S15. [6] Moore J. M. and Howard A. D. (2005) *J. Geophys. Res., 110,* E04005. [7] Morgan A. M. et al. (2014) *Icarus, 229,* 131-156. [8] Grotzinger J. P. et al. (2015), *Science, 350,* aac7575. [9] Palucis M. C. et al. (2016) *J. Geophys. Res., 121,* 472-496. [10] Chan N. H. et al. (2018) *J. Geophys. Res., 123,* 2138-2150. [11] Horvath D. G. and Andrews-Hanna J. C. (2017) *Geophys. Res. Letters, 44,* 8196-8204.

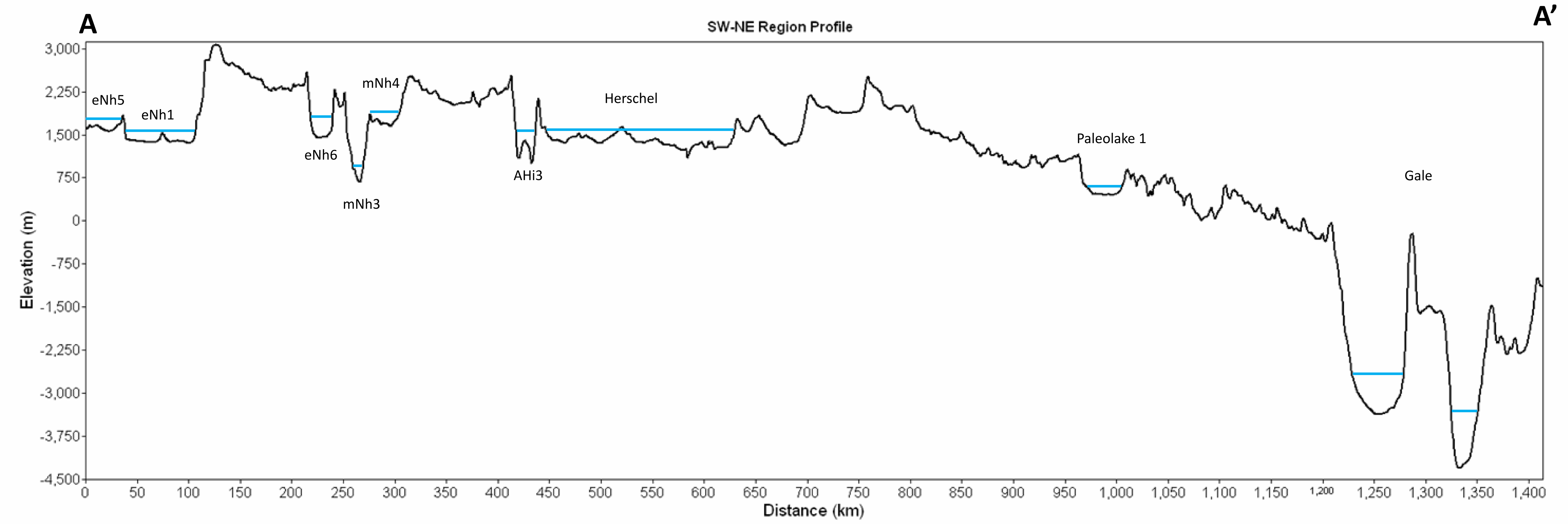

Fig. 3: Cross-section of transect line (Fig. 2), with crater names and endpoints A and A' marked. Inferred paleolake levels (average VNT elevation) marked in blue.

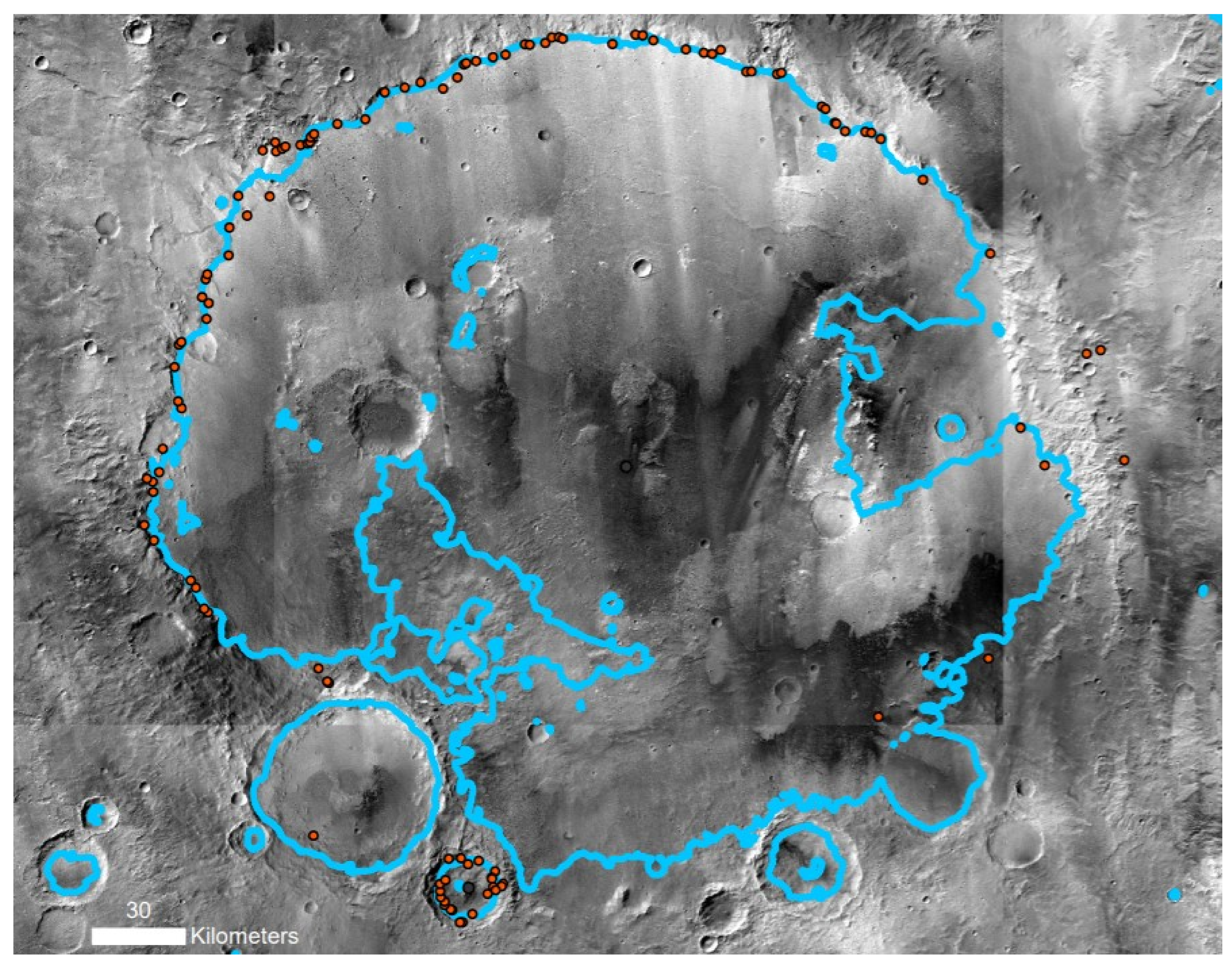

Fig. 4: Herschel crater, with contour of inferred paleolake level (~1600 m) marked in blue, and valley network terminations marked in orange.

Observations and Implications

- Common elevations (within error of the MOLA DEM) of VNTs were observed in all craters we investigated
- We did not observe a systematic morphologic change in crater wall topography that would control valley network incision- this suggests that VNTs might be recording paleo-lake levels
- Most VNTs seem to correspond to an aridity index of 1.5 in the Horvath and Andrews-Hanna (2017) model, though VNTs on the north side of Gale seem to correspond to an aridity index of 3.5 (Fig. 7).

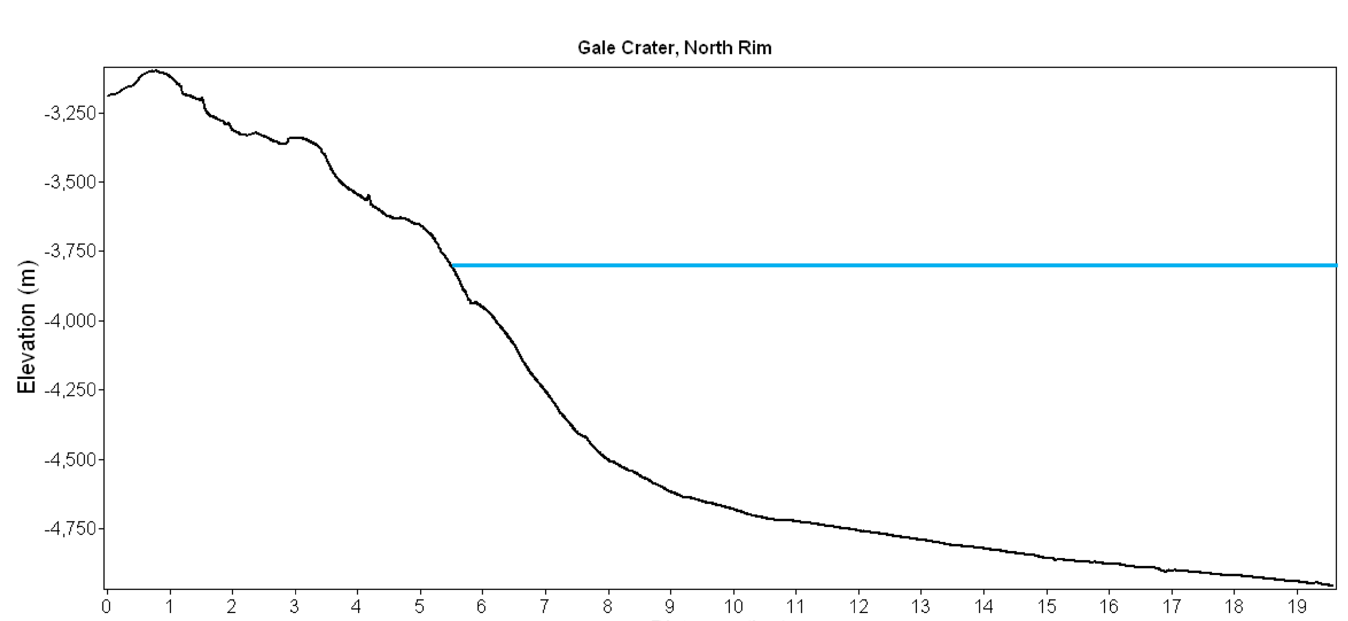

Fig. 5: Topographic profile of north side of Gale crater CTX DEM, with inferred paleolake level indicated in blue.

Comparison with Groundwater Model from Horvath and Andrews-Hanna (2017)

We compared our mapped VNTs to groundwater modeling data from Horvath and Andrews-Hanna (2017) (Fig. 6, 7). They modeled groundwater flow in the Gale region at a range of aridity indices (a_i = evaporation rate / precipitation rate), then compared the resulting lake levels in Gale to Gale paleo-lake levels from Palucis et al (2016).

The model uses a precipitation rate of 160 mm/yr, a permeability of $3 * 10^{-13}$ m^2, and a shape parameter (for use in the Budyko relationship) of 1.6.

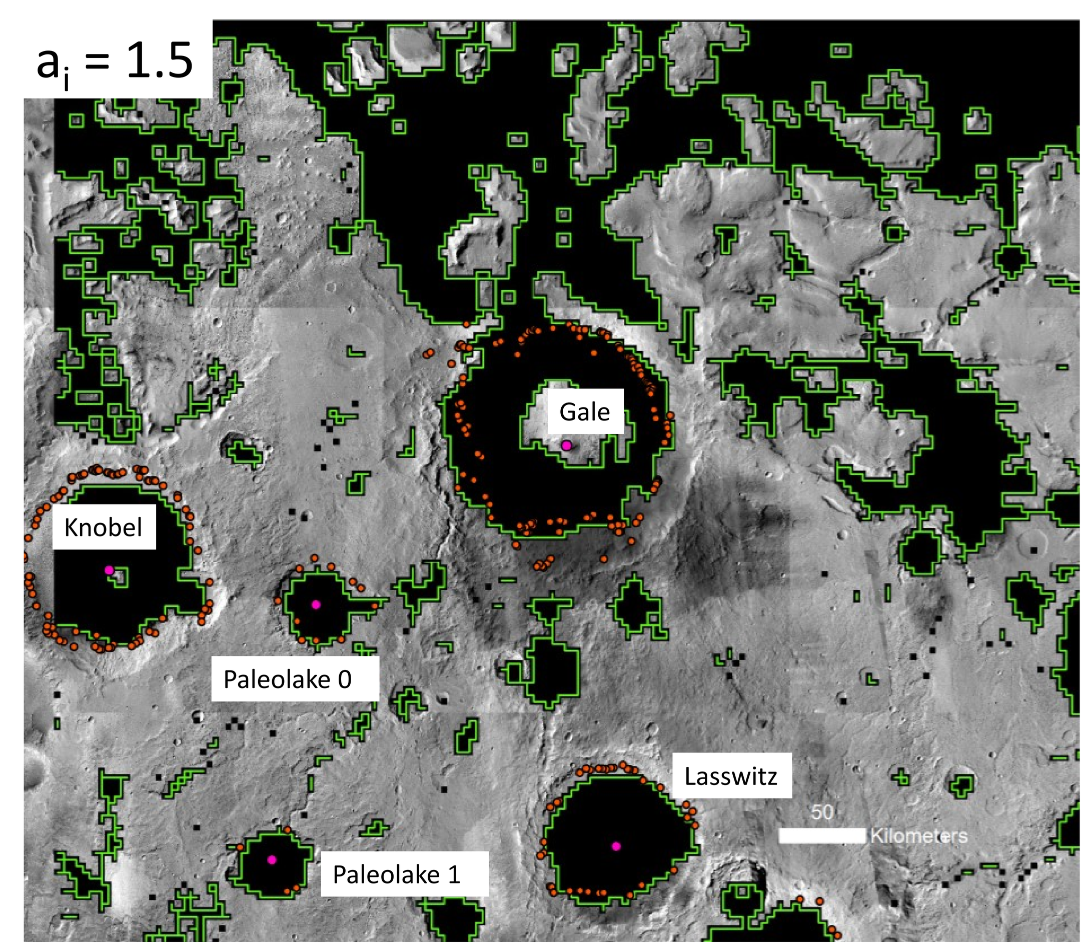

Fig. 6: Horvath and Andrews-Hanna (2017) groundwater output compared to mapped VNTs (orange); black areas indicate where the groundwater table intersects the surface (i.e., ponding occurs). This corresponds to an aridity index of 1.5.

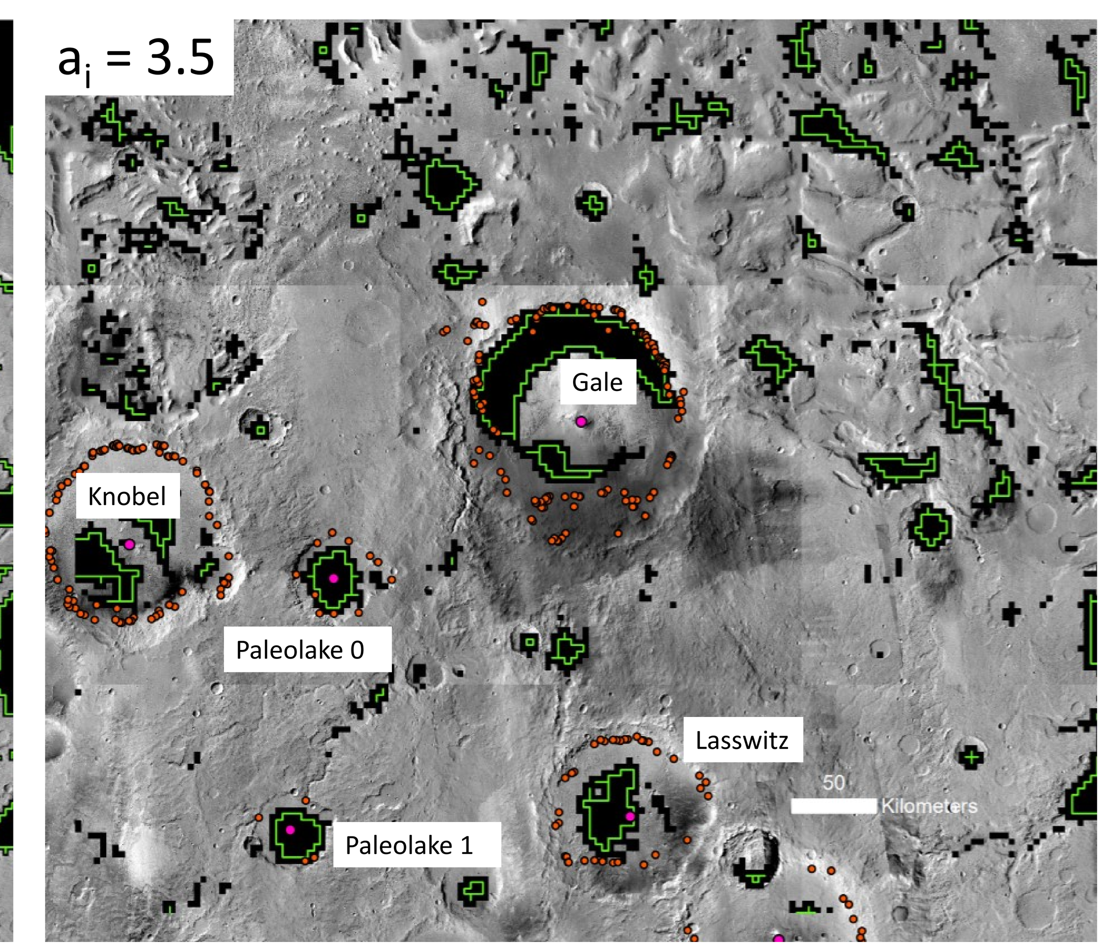

Fig. 7: Horvath and Andrews-Hanna (2017) groundwater output compared to mapped VNTs (orange); black areas indicate where the groundwater table intersects the surface (i.e., ponding occurs). This corresponds to an aridity index of 3.5.

Conclusions and Future Work

- VNTs may be useful for identifying potential Martian paleo-lakes.
- Comparison with Horvath and Andrews-Hanna (2017) groundwater modeling data indicates that most mapped VNTs seem to correspond to an aridity index of 1.5, slightly more humid than those identified for Gale lake stands based on deltaic features (Palucis et al, 2016). However, VNTs on the north side of Gale crater do seem to fit with an aridity index of 3.5 (consistent with deltaic features), possibly due to drying in the region.
- To better understand relative timing and the magnitude of surface- and groundwater flow in this region we will perform crater counting on the floor and rims of our proposed paleo-lakes, as well as perform geomorphic analysis of the valley networks to estimate surface flow runoff and discharges. We will compare the latter to surface flow outputs from the Horvath and Andrews-Hanna model to better constrain their combined surface-groundwater flow model.